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COMPARATIVE TESTS OF BY-PRODUCT COKE AND OTHER FUELS FOR HOUSE-HEATING BOILERS

BY
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INTRODUCTION.

This report is one of a series published by the Bureau of Mines for the purpose of disseminating information regarding the fuels best adapted for heating houses. A knowledge of the value of the different available fuels helps the householder to select the one that will heat his house at the lowest cost and with the least waste. Such fuel should be clean and smokeless, and should keep the house at an even temperature, with little attention to the fire. Anthracite suitably sized possesses these properties to a large degree and has been used for this purpose for a long time, particularly near the anthracite mines. Many thickly populated districts are so far from these mines, however, that anthracite can be obtained only at a high price, and the bituminous coal that is available is smoky and does not usually maintain a uniform temperature without frequent attention to the fire. By-product coke, in small sizes, is a good substitute for anthracite. It is clean, burns without smoke, and gives a uniform heat. As it is made from bituminous coal, and the bituminous coal beds are very extensive, it seems possible to provide smokeless fuel in the form of by-product coke for practically the entire country.

The Bureau of Mines has issued several publications [1] on the combustion of coal at low rates, in boilers and furnaces: This paper gives the result of tests that were made to compare by-product coke, bituminous coal and anthracite as fuels for small boilers.

[1] BLIZARD, JOHN, NEIL, J., and HOUGHTON, F. C. Value of coke, anthracite, and bituminous coal for generating steam in a low-pressure cast-iron boiler. Tech. Paper 303, Bureau of Mines, 1921, 56 pp.

FLAGG, S. B. Firing bituminous coals in large house-heating boilers. Tech. Paper. 180, Bureau of Mines, 1917, 22 pp.

KREISINGER, HENRY, AUGUSTINE, C. E., and KATZ, S. H. Low-rate combustion in fuel beds of hand-fired furnaces. Tech. Paper 139, Bureau of Mines, 1918, 54 pp.

KREISINGER, HENRY, and FIELDNER, A. C. Why and how coke should be used for domestic heating. Tech. Paper 242, Bureau of Mines, 1919, 20 pp.

RANDALL, D. T. Tests of coal and briquettes as fuel for house-heating boilers. Bull. 27, Bureau of Mines, 1911, 44 pp.

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SCOPE OF TESTS.

The first series of tests, 27 in all, was made in the fuels laboratory of the Pittsburgh experiment station with small steam boilers suitable for heating a seven or eight room house. The fuels were by-product coke, anthracite, and Pittsburgh coal. The second series, 17 tests, was made in the fuels laboratory—built for these tests—at the Minneapolis station of the Bureau of Mines, with a small steam boiler of similar size to that used in the tests at Pittsburgh, and with another larger boiler of the type used in heating small apartment-houses. The fuels used were by-product coke, anthracite, and Illinois coal.

OPERATION OF BOILER DURING TESTS.

As far as possible, the boiler was operated as it would be in actually heating a house. A test usually lasted from Monday morning until Friday or Saturday morning; and at night the fuel was burned at lower rates than in the day time. A more detailed description of the method of operation will be found under "Method of Conducting Tests."

SUMMARY OF RESULTS.

A brief summary of the results is given in Table 1, which shows that the efficiency was as high with by-product coke as with anthracite. In fact, the two Capitol boilers gave somewhat higher efficiencies with coke than with anthracite. The efficiencies obtained with Pittsburgh and Illinois coal were 8 to 20 per cent lower than that obtained with by-product coke.

The relative quantities of bituminous coal, coke, and anthracite needed to maintain a house at a comfortable temperature during the winter depend upon the calorific values of the fuels as well as the thermal efficiencies; and the calorific values of all three fuels may vary considerably, owing principally to their variable ash and moisture content. The Pittsburgh tests showed that about 10 tons of Pittsburgh coal was equal to 9 tons of coke, or 8½ tons of anthracite when the fuels were burned in the Arco boiler; and to 10 tons of coke or 9 tons of anthracite when burned in the Dunning boiler.

The Minneapolis tests showed that about 10 tons of Illinois coal was equal to 7½ tons of coke or anthracite when burned in the smaller Capitol Winchester boiler, and equal to 8½ tons of coke or anthracite when burned in the larger Capitol boiler.

With the same attention to the fire, coke gives a much more uniform temperature than bituminous coal. In addition, coke is a clean fuel and makes neither smoke nor soot, an advantage difficult to express in exact figures. It is nearly as good a fuel as the domestic sizes of anthracite, and if anthracite is unavailable at reasonable prices a by-product coke makes a good substitute.

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TABLE 1.—*Summary of results.*

Efficiency obtained with different fuels when the boilers were absorbing heat at the rate of 2,500 B. t. u. per square foot of heating surface per hour.

Name of boiler.	Size.		Thermal efficiency. Heat absorbed by water in boiler in per cent of heat in coal fired.			
			Fuels.			
	Heating surface, square feet.	Grate area, square feet.	By-product coke.	Anthracite coal.	Pittsburgh coal.	Illinois coal.
Arco, No. 6-23-S	39	2.9	70	70	54	.....
Dunning, No. 303-S	46	3.6	70	70	62	.....
Capitol Winchester, No. 3450	33	3.3	70	69	.....	49
Capitol, No. 257	106	8.6	66	60	.....	50

DESCRIPTION OF BOILERS.

Fifteen tests of the Pittsburgh series were made with an Arco boiler No. 6–23–S, manufactured by the American Radiator Co., and 12 tests with a Dunning boiler No. 303–S, made by the New York Central Iron Works Co. Plate I, *A*, shows the two boilers set up in the laboratory and equipped for the tests. The one in front is the Arco, and the one in the rear is the Dunning.

Of the Minneapolis series, 9 tests were made with the Capitol Winchester boiler No. 3450, and 8 with the Capitol boiler No. 257. Both boilers were made by the United States Radiator Corporation. Plate I, *B*, shows the boilers set up for tests in the laboratory at Minneapolis. The boiler on the left is No. 3450, and the one in the center is No. 257.

Table 2 gives the principal dimensions of the four boilers.

TABLE 2.—*Principal dimensions of boilers used in the tests.*

Kind of boiler	Arco.	Dunning.	Capitol Winchester No. 3450.	Capitol No. 257.
Manufacturers' rating, square feet of radiation	650	600	575	1,600
Total heating surface, square feet	39	46	33	106
Grate area, do	2.9	3.6	3.3	8.6
Nominal diameter of grate, inches	23	26	24½	27 x 47
Height of furnace—grate to crown, do	20	36	28½	22
Width of air spaces in grate bars, do	½	½	⅝	¼
Volume between grate and center of fire door, cubic feet	4.1	4.2	4.3	12.5

DESCRIPTION OF FUELS.

The quality of the fuels used in the Pittsburgh series of tests was as follows:

The anthracite was taken from the bureau stock. It was a mixture of egg and nut sizes, and was considerably cleaner than that ordinarily obtained in the Pittsburgh market.

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The Pittsburgh coal was also a mixture of egg and nut sizes. It was purchased from a local coal dealer, and was of good average quality.

The by-product coke was furnished by the Carnegie Steel Co., and was made in that company's by-product plant at Clairton, Pa. It was domestic-size coke, similar to nut-size anthracite, and was taken from a stock bin containing a mixture of 60 per cent 21-hour and 40 per cent 19-hour by-product coke. The coal from which the coke was made was a mixture of several coals from the Klondike region near Pittsburgh.

The anthracite and Illinois coal used in the Minneapolis tests were purchased from local coal dealers. They were a mixture of egg and nut sizes, and were of good average quality.

The by-product coke was purchased from the Minnesota By-product Co., St. Paul, Minn., and was made from eastern coal. It was of domestic size, similar to the nut-size anthracite.

METHOD OF CONDUCTING THE TESTS.

Each test lasted about five days. During each 24 hours the fires were run for a period of 8 hours at low rating, similar to night running in actual heating service; no coal was fired, and the fire was not attended to. During the other 16 hours the fires were run to develop a definite rating of the boiler, simulating day running conditions. Two to six tests were made with each fuel at different ratings of the boiler and with the periods between firings as long as possible. The length of these periods depended on the amount of coal that could be put into the furnace at one time and the rate at which the coal was burned. On the low-rating tests these periods on the three small boilers were about 8 hours long, and on the high ratings 3 to 4 hours long. Practically no attention was given to the fires between the firings. On the larger size boiler, the firings were made 30 to 45 minutes apart, as is the practice in apartment houses.

Steam was generated under a pressure of 1 to 4 pounds, and discharged into the atmosphere. To prevent water from being blown out with the steam, a large steam separator was placed in the steam line. Water was weighed and fed into the boiler every half hour to keep its height as nearly constant as it would be under actual heating conditions.

The fuel was weighed for each firing, and the ash and clinkers were weighed as they were removed from the ash pit or furnace. Other observations necessary to compute a complete heat balance were made.

STARTING THE TESTS.

The heating surfaces of the boilers were thoroughly cleaned before each test. The fire was started with kindling wood and run for about an hour to get the steam pressure up. About 10 minutes before a

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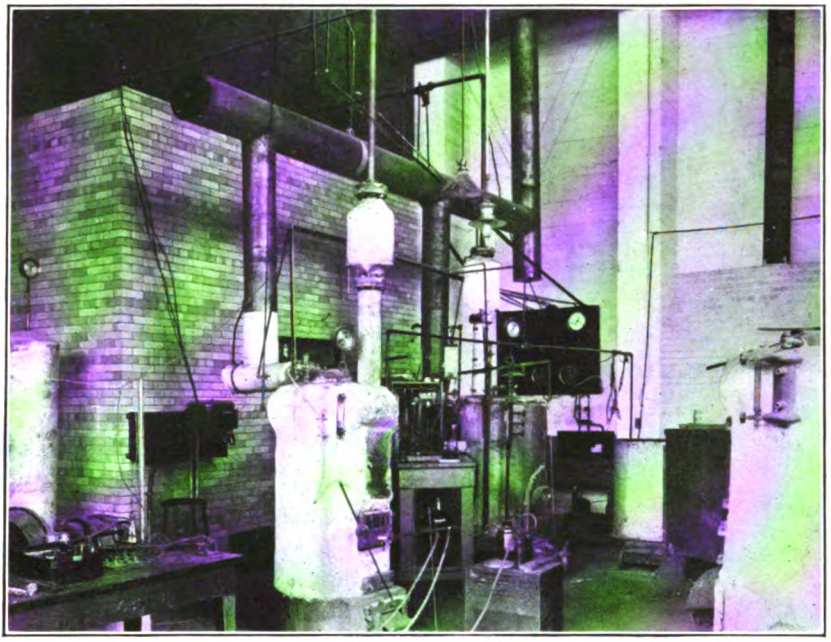
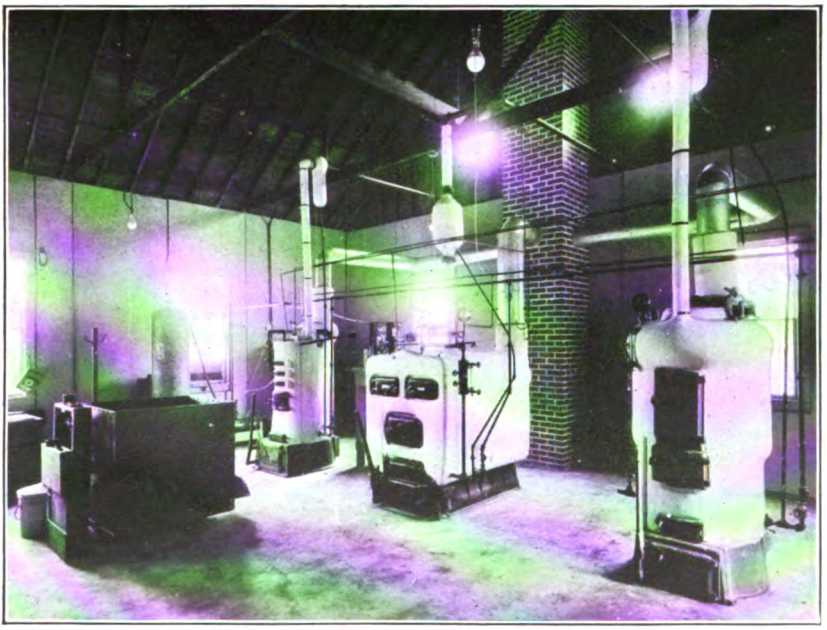


A. ARCO AND DUNNING BOILERS EQUIPPED FOR TESTS AT PITTSBURGH STATION. ARCO BOILER IN FRONT; DUNNING BOILER IN REAR.



B. CAPITOL AND CAPITOL WINCHESTER BOILERS EQUIPPED FOR TESTS AT MINNEAPOLIS FUEL LABORATORY. CAPITOL WINCHESTER AT LEFT; CAPITOL IN CENTER.

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test started, the grate was shaken and all ash removed from furnace and ash pit. When the test was started, the thickness of the fuel, as well as the height of water in the boiler, was measured and noted.

CLOSING THE TESTS.

At the close of a test, an endeavor was made to have the same amount of fuel in the furnace as at the start, but this amount was difficult to determine, because the fuel bed contained some clinker and large pieces of ash which accumulated during the test and could not be shaken through the grate. About 10 minutes before the test was closed, the grate was shaken and all ash removed from the ash pit. After the test was closed, the fire was dumped and all clinker and large pieces of ash were picked out and weighed. Of the remaining partly burned fuel, an amount equivalent to the thickness of fire at the start of the run was allowed to represent the quantity of fuel to be left on the grate at the end of the test. Any fuel in excess of this amount was weighed and subtracted from the fuel charged to the test. When the quantity of fuel dumped was less than the equivalent of the thickness of the fuel bed when the test was started, enough was added and charged to the test.

The water in the boiler was brought to the same level as at the start of the test.

METHOD OF FIRING AND OF CLEANING FIRES.

Immediately before firing, the grate was shaken and all large pieces of clinker were removed from the furnace with a hook; the fire was then leveled, and a new charge of fuel added. When the coke was tested, practically the entire available space in the furnace was filled with the fuel at each firing, so that the amount of the fuel that could be fired at one time and the period between firings were determined by the volume of the furnace. Coke was the bulkiest of the fuels tested, and, therefore, with the same filling of the furnace a smaller weight of coke than of either anthracite or bituminous coal could be fired.

To compare the results of the tests of the different fuels more readily, an effort was made, as far as possible, to fire about the same weight of each fuel at one time, and to make the period between firings of nearly the same length. But these periods of equal time were not always practicable; and in some of the tests with coke, though the rating of the boiler was the same, the periods were shorter than in the tests with other fuels because the furnace held too little coke.

RESULTS OF TESTS.

The results of the tests are given in Tables 3 to 6. Each test has been computed as one unit; that is, the results include the 8-hour night periods as well as the 16-hour day periods. It was found impracticable to compute the results separately for each group of periods.

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TABLE 3.—*Tests with "Arco" boiler No. 6-23-S.*

Reference number.	General particulars.	By-product coke.						Anthracite.			Pittsburgh bituminous coal.					
1	Number o ftrial	1	13	2	3	14	15	10	11	12	16	17	18	22	23	26
2	Duration of trial, hours	96	120	120	119.17	120	120	95	96	120	120	88.5	120	104	104	120
3	Average interval between firings, minutes	230	379	277	286	360	277	356	274	225	480	221	232	480	297	225
4	Fuel fired per hour, pounds	10	11	15	17	16	23	11	14	19	10	18	22	10	17	21
	FUEL.															
5	Ultimate analysis as fired:															
	Hydrogen, per cent	0.69	0.74	0.59	0.87	0.72	0.76	2.92	2.87	2.89	5.14	5.13	5.14	5.15	5.14	5.15
	Carbon, per cent	78.61	78.18	78.28	77.20	78.33	78.00	78.77	79.35	79.08	73.59	73.80	73.59	73.48	73.64	73.46
	Nitrogen, per cent	1.26	1.25	1.25	1.24	1.26	1.25	0.83	0.84	0.84	1.33	1.33	1.33	1.33	1.33	1.33
	Oxygen, per cent	1.42	1.90	1.80	2.98	1.73	2.10	4.91	4.29	4.58	9.60	9.36	9.60	9.71	9.54	9.73
	Sulphur, per cent	0.88	0.88	1.01	0.87	0.88	0.88	1.00	1.00	1.00	1.90	1.91	1.90	1.90	1.90	1.90
	Ash, per cent	17.14	17.05	17.07	16.84	17.08	17.01	11.57	11.65	11.61	8.44	8.47	8.44	8.43	8.45	8.43
6	Proximate analysis as fired:															
	Moisture, per cent	0.79	1.34	1.21	2.57	1.15	1.56	4.09	3.38	3.71	2.37	2.09	2.37	2.52	2.31	2.55
	Volatile matter, per cent	2.80	2.78	2.79	2.75	2.79	2.78	6.36	6.41	6.38	37.16	37.26	37.16	37.10	37.18	37.09
	Fixed carbon, per cent	79.27	78.83	78.93	77.84	78.98	78.65	77.98	78.56	78.30	52.03	52.18	52.03	51.95	52.06	51.93
	Ash, per cent	17.14	17.05	17.07	16.84	17.08	17.01	11.57	11.65	11.61	8.44	8.47	8.44	8.43	8.45	8.43
	Fuel ratio F.C./V.M	28.3	28.4	28.3	28.3	28.3	28.3	12.3	12.3	12.3	1.4	1.4	1.4	1.4	1.4	1.4
7	Calorific value of fuel per pound:															
	As fired, B. t. u	11,756	11,690	11,706	11,544	11,713	11,664	12,639	12,733	12,689	13,220	13,258	13,220	13,200	13,228	13,196
	Moisture and ash free, B. t. u	14,324	14,324	14,324	14,324	14,324	14,324	14,985	14,985	14,985	14,823	14,823	14,823	14,823	14,823	14,823
8	Total fuel fired during trial, pounds	961	1,312	1,806	2,052	1,977	2,802	1,014	1,370	2,324	1,236	1,553	2,609	1,034	1,776	2,548
	ASH AND REFUSE.															
9	Total ash and refuse removed during trial, pounds	181	242	269	409	345	501	178	233	361	99	139	255	102	163	254
10	Carbonaceous matter in ash and refuse, per cent	8.29	7.40	8.92	11.20	8.10	9.18	36.50	34.30	19.70	17.17	14.40	15.92	19.61	15.34	19.29
11	Ash and refuse removed, per cent fuel as fired	18.83	18.45	14.89	19.93	17.45	17.88	17.55	17.01	15.53	8.01	8.95	9.77	9.86	9.18	9.97
	DRAFT.															
12	Draft in ash pit, inches of water	0.056	0.052	0.035	0.021	0.054	0.047	0.042	0.022	0.005	0.019	0.027	0.030	0.028	0.088	0.060
13	Draft in furnace, inches of water	0.064	0.065	0.053	0.048	0.080	0.094	0.073	0.067	0.086	0.036	0.064	0.084	0.061	0.160	0.175
	AIR.															
15	Temperature air entering ash pit, ° F	76	80	81	80	85	90	81	83	84	82	84	88	78	81	84
16	Excess air in flue gas, per cent	70	92	72	84	80	71	106	91	74	57	83	101	188	186	177

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	FLUE GASES.														
17	Analysis of dry flue gases by volume:														
	Carbon dioxide, per cent	11.7	10.1	11.3	10.7	10.8	11.3	8.9	9.8	10.9	10.5	9.6	8.8	5.7	6.1	6.2
	Oxygen, per cent	8.7	10.1	8.8	9.6	9.4	8.8	10.9	10.1	9.0	7.8	9.7	10.7	13.9	13.8	13.6
	Carbon monoxide, per cent	0.4	0.5	0.6	0.5	0.5	0.3	0.5	0.3	0.3	0.5	0.3	0.3	0.3	0.2	0.2
	Nitrogen (by difference), per cent	79.2	79.3	79.3	79.2	79.3	79.6	79.7	79.8	79.8	81.2	80.4	80.2	80.1	79.9	80.0
18	Mean temperature of flue gases leaving boiler, ° F	456	427	534	549	574	654	453	504	647	600	762	809	501	621	617
	STEAM AND FEED WATER.															
19	Gauge pressure, pounds per square inch	4	4	3	3	3	3	3	3	3	3	3	3	2	2	3
20	Temperature of feed water, ° F	69	77	66	67	79	82	77	77	78	77	76	77	71	72	70
	RATES.															
21	Heat transferred to water per hour, 1,000 B. t. u	85	90	117	125	133	171	94	121	153	78	131	155	68	114	137
22	Heat transferred to water per square foot of heating surface per hour, B. t. u	2,170	2,290	2,990	3,180	3,390	4,360	2,410	3,090	3,900	2,000	3,340	3,960	1,740	2,910	3,510
23	Fuel fired per square foot grate surface per hour, pounds	3.4	3.8	5.2	5.9	5.7	8.0	3.7	4.9	6.7	3.5	6.0	7.5	3.4	5.9	7.3
	HEAT BALANCE, PER POUND FUEL AS FIRED.															
24	Heat transferred to water, B. t. u	8,478	8,215	7,775	7,241	8,062	7,319	8,849	8,497	7,890	7,610	7,461	7,132	6,872	6,667	6,474
25	Heat carried away by steam in flue gases, B. t. u	76	80	67	99	82	89	320	320	340	596	630	639	577	601	600
26	Heat carried away by dry flue gases, B. t. u.	1,462	1,510	1,767	1,890	2,004	2,244	1,710	1,837	2,301	2,040	2,972	3,403	2,972	3,557	3,519
27	Heat lost by not burning carbon monoxide, B. t. u	259	368	394	340	345	200	391	222	207	333	223	241	363	233	227
28	Heat lost by not burning carbonaceous matter from ash pit and grate, B. t. u	228	200	194	327	207	240	936	853	446	201	188	227	282	206	281
29	Undetermined losses, B. t. u	1,253	1,317	1,509	1,647	1,013	1,572	433	1,004	1,505	2,440	1,784	1,578	2,134	1,864	2,095
	Total and calorific value of fuel, B. t. u.	11,756	11,690	11,706	11,544	11,713	11,664	12,639	12,733	12,689	13,220	13,258	13,220	13,200	13,228	13,196
	HEAT BALANCE, PER CENT HEAT IN FUEL AS FIRED.															
30	Heat transferred to water (thermal efficiency)	72.1	70.3	66.4	62.7	68.8	62.7	70.0	66.7	62.2	57.6	56.3	53.9	52.1	50.4	49.1
31	Heat carried away by steam in flue gases	0.6	0.7	0.6	0.9	0.7	0.8	2.5	2.5	2.7	4.5	4.8	4.8	4.4	4.5	4.5
32	Heat carried away by dry flue gases	12.4	12.9	15.1	16.4	17.1	19.2	13.5	14.4	18.1	15.4	22.4	25.7	22.5	27.6	26.7
33	Heat lost by not burning carbon monoxide	2.2	3.1	3.4	2.9	2.9	1.7	3.1	1.7	1.6	2.5	1.7	1.8	2.8	1.8	1.7
34	Heat lost by not burning carbonaceous matter from ash pit and grate	1.9	1.7	1.7	2.9	1.8	2.1	7.4	6.7	3.5	1.5	1.4	1.7	2.1	1.6	2.1
35	Undetermined losses	10.8	11.3	12.8	14.2	8.7	13.5	3.5	8.0	11.9	18.5	13.4	12.1	16.1	14.1	15.9
	Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

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TABLE 4.—*Tests with Dunning boiler No. 303–S.*

Reference number.	General particulars.	By-product coke.			Anthracite.				Pittsburgh bituminous.				
1	Number of trial	4	5	6	7	27	8	9	19	20	21	24	25
2	Duration of trial, hours	119.17	119.83	96	120	120	120	116.5	120	96	120	118.5	120
3	Average interval between firings, minutes	477	327	303	480	480	424	333	480	339	277	474	360
4	Fuel fired per hour, pounds	9	15	20	9	13	14	18	11	14	18	10	15
	FUEL.												
5	Ultimate analysis as fired:												
	Hydrogen, per cent	0.74	0.72	0.78	2.90	2.86	2.91	2.96	5.15	5.16	5.15	5.13	5.15
	Carbon, per cent	78.20	78.34	77.87	79.00	79.50	78.94	78.50	73.47	73.44	73.52	73.77	73.54
	Nitrogen, per cent	1.25	1.26	1.25	0.84	0.84	0.84	0.83	1.33	1.33	1.33	1.33	1.33
	Oxygen, per cent	1.88	1.72	2.25	4.66	4.12	4.72	5.19	9.72	9.74	9.66	9.39	9.64
	Sulphur, per cent	.88	.88	.87	1.00	1.01	1.00	.99	1.90	1.90	1.90	1.91	1.90
	Ash, per cent	17.05	17.08	16.98	11.60	11.67	11.59	11.53	8.43	8.43	8.44	8.47	8.44
6	Proximate analysis as fired:												
	Moisture, per cent	1.31	1.13	1.73	3.81	3.20	3.88	4.42	2.53	2.57	2.47	2.13	2.44
	Volatile matter, per cent	2.78	2.79	2.77	6.38	6.42	6.37	6.34	37.10	37.08	37.12	37.25	37.13
	Fixed carbon, per cent	78.86	79.00	78.52	78.21	78.71	78.16	77.71	51.94	51.92	51.97	52.15	51.99
	Ash, per cent	17.05	17.08	16.98	11.60	11.67	11.59	11.53	8.43	8.43	8.44	8.47	8.44
	Fuel ratio, F. C./V. M	28.4	28.3	28.3	12.3	12.3	12.3	12.3	1.4	1.4	1.4	1.4	1.4
7	Calorific value of fuel per pound:												
	As fired, B. t. u	11,694	11,715	11,644	12,676	12,756	12,667	12,596	13,198	13,193	13,207	13,253	13,211
	Moisture and ash, free, B. t. u	14,324	14,324	14,324	14,985	14,985	14,985	14,985	14,823	14,823	14,823	14,823	14,823
8	Total fuel fired during trial, pounds	1,125	1,826	1,964	1,046	1,531	1,693	2,128	1,260	1,329	2,166	1,235	1,850
	ASH AND REFUSE.												
9	Total ash and refuse removed during trial, pounds	199	349	394	217	266	287	373	132	112	219	127	179
10	Carbonaceous matter in ash and refuse, per cent	13.57	15.76	15.99	36.41	33.08	34.15	35.66	20.45	18.75	19.18	24.41	15.08
11	Ash and refuse removed; per cent fuel as fired	17.69	19.11	20.06	20.75	17.37	16.95	17.53	10.48	8.43	10.11	10.28	9.68
	DRAFT.												
12	Draft in ash pit, inches of water	0.026	0.044	0.025	0.022	0.051	0.013	0.049	0.025	0.032	0.029	0.017	0.049
13	Draft in furnace, inches of water	0.029	0.053	0.045	0.033	0.093	0.042	0.075	0.037	0.056	0.061	0.033	0.070
14	Draft in stack, inches of water	.....	.....	.....	.....	0.100	.....	.....	.....	.....	0.100	0.037	0.089
	AIR.												
15	Temperature air entering ash pit, °F	79	77	85	86	84	84	86	78	76	84	83	84
16	Excess air in flue gas, per cent	103	72	57	93	104	48	60	81	70	124	134	95

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	FLUE GASES.											
17	Analysis of dry flue gases by volume:											
	Carbon dioxide, per cent	9.6	11.4	12.0	9.7	9.3	12.7	11.5	8.2	10.0	7.4	7.2	8.6
	Oxygen, per cent	10.7	8.8	7.7	10.2	10.8	6.9	8.0	9.7	8.8	11.8	12.2	10.4
	Carbon monoxide, per cent	0.5	0.5	0.6	0.5	0.2	0.4	0.5	0.6	0.9	0.6	0.4	0.7
	Nitrogen (by difference), per cent	79.2	79.3	79.7	79.6	79.7	80.0	80.0	81.5	80.3	80.2	80.2	80.3
18	Mean temperature flue gases leaving boiler, °F	199	236	264	214	254	237	259	215	245	271	278	296
	STEAM AND FEED WATER.											
19	Gauge pressure, pounds per sq. in	4	4	5	4	4	3	4	3	3	3	2	4
20	Temperature of feed water, °F	70	68	69	75	73	77	79	76	73	76	74	74
	RATES.											
21	Heat transferred to water per hour, 1,000 B. t. u	75	127	159	75	114	129	172	86	116	143	81	123
22	Heat transferred to water per square foot of heating surface per hour, B. t. u	1,630	2,770	3,470	1,640	2,480	2,810	3,730	1,870	2,530	3,100	1,770	2,670
23	Fuel fired per square foot grate surface per hour, pounds	2.6	4.1	5.5	2.4	3.5	3.8	5.0	2.8	3.8	4.9	2.8	4.2
	HEAT BALANCE PER POUND FUEL AS FIRED.											
24	Heat transferred to water, B. t. u	7,966	8,366	7,795	8,656	8,940	9,155	9,399	8,192	8,392	7,907	7,815	7,955
25	Heat carried away by steam in flue gases, B. t. u	73	72	79	287	288	291	298	513	522	523	523	528
26	Heat carried away by dry flue gases, B. t. u	540	607	641	537	790	518	628	660	667	992	1,084	979
27	Heat lost by not burning carbon monoxide, B. t. u	381	321	361	355	158	227	306	494	602	545	381	551
28	Heat lost by not burning carbonaceous matter from ash pit and grate, B. t. u	350	440	468	1,103	839	845	913	313	231	283	366	213
29	Undetermined losses, B. t. u	2,384	1,909	2,300	1,738	1,741	1,631	1,052	3,026	2,779	2,957	3,084	2,985
	Total and calorific value of fuel, B. t. u	11,694	11,715	11,644	12,676	12,756	12,667	12,596	13,198	13,193	13,207	13,253	13,211
	HEAT BALANCE, PER CENT HEAT IN FUEL AS FIRED.											
30	Heat transferred to water (thermal efficiency)	68.1	71.4	66.9	68.3	70.1	72.3	74.6	62.1	63.6	59.9	59.0	60.2
31	Heat carried away by steam in flue gases	0.6	0.6	0.7	2.3	2.3	2.3	2.4	3.9	4.0	4.0	3.9	4.0
32	Heat carried away by dry flue gases	4.6	5.2	5.5	4.2	6.2	4.1	5.0	5.0	5.1	7.5	8.2	7.4
33	Heat lost by not burning carbon monoxide	3.3	2.7	3.1	2.8	1.2	1.8	2.4	3.7	4.6	4.1	2.9	4.2
34	Heat lost by not burning carbonaceous matter from ash pit and grate	3.0	3.8	4.0	8.7	6.6	6.7	7.2	2.4	1.8	2.1	2.8	1.6
35	Undetermined losses	20.4	16.3	19.8	13.7	13.6	12.8	8.4	22.9	20.9	22.4	23.2	22.6
	Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

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TABLE 5.—*Tests with Capitol Winchester boiler No. 3450.*

Reference number.	General particulars.	Coke.				Anthracite coal.			Illinois bituminous coal.	
1	Number of trial	2	3	4	5	6	20	21	9	10
2	Duration of trial, hours	120	120	120	120	120	120	120	120	120
3	Average interval between firings, minutes	277	145	164	258	556	402	289	344	362
4	Fuel fired per hour, pounds	8	15	19	9	8	15	18	10	13
	FUEL.									
5	Ultimate analysis as fired:									
	Hydrogen, per cent	1.10	1.04	1.11	1.00	2.47	2.54	2.64	5.21	5.14
	Carbon, per cent	78.01	78.57	77.92	78.84	75.40	69.64	77.46	66.61	67.44
	Nitrogen, per cent	.84	.85	.84	.85	.89	.74	.79	1.53	1.55
	Oxygen, per cent	5.85	5.25	5.95	4.96	4.56	5.49	4.47	16.21	15.30
	Sulphur, per cent	.88	.88	.88	.89	1.20	.62	.83	.97	.98
	Ash, per cent	13.32	13.41	13.30	13.46	15.48	20.97	13.81	9.47	9.59
6	Proximate analysis as fired:									
	Moisture, per cent	6.75	6.08	6.86	5.76	3.26	3.61	2.94	8.72	7.58
	Volatile matter, per cent	1.65	1.66	1.65	1.67	5.61	6.23	5.72	33.15	33.57
	Fixed carbon, per cent	78.28	78.85	78.19	79.11	75.65	69.19	77.53	48.66	49.26
	Ash, per cent	13.32	13.41	13.30	13.46	15.48	20.97	13.81	9.47	9.59
	Fuel ratio F. C./V. M	47.4	47.5	47.4	47.4	13.48	11.11	13.55	1.47	1.47
7	Calorific value of fuel per pound:									
	As fired, B. t. u	11,414	11,496	11,400	11,535	12,071	11,172	12,436	11,817	11,965
	Moisture and ash free, B. t. u	14,279	14,279	14,279	14,279	14,855	14,814	14,938	14,445	14,445
8	Total fuel fired during trials, pounds	992	1,853	2,315	1,102	953	1,798	2,177	1,180	1,582
	ASH AND REFUSE.									
9	Total ash and refuse removed during trial, pounds	123	231	254	128	155	500	507	116	180
10	Carbonaceous matter in ash and refuse, per cent	7.32	3.03	1.97	7.03	8.39	29.40	29.78	9.48	7.22
11	Ash and refuse removed, per cent fuel as fired	12.40	12.47	10.97	11.62	16.26	27.81	23.29	9.83	11.38
	DRAFT.									
12	Draft in ash pit, inches of water	0.038	0.053	0.048	0.047	.041	.051	.047	.014	.012
13	Draft in furnace, inches of water	0.028	0.051	0.059	0.046	.032	.060	.078	.016	.021
14	Draft in stack, inches of water									
	AIR.									
15	Temperature air entering ash pit, °F	81	92	86	70	73	74	76	69	74
16	Excess air in flue gas, per cent	66	64	68	134	81	83	60	160	134

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	FLUE GASES.									
17	Analysis of dry flue gases by volume:									
	Carbon dioxide, per cent	11.8	11.5	10.9	8.1	10.2	10.6	12.1	7.3	7.4
	Oxygen, per cent	8.4	8.3	8.6	12.1	9.5	9.6	7.9	13.0	12.2
	Carbon monoxide, per cent	.2	.3	.5	.2	.2	.2	.4	.2	.2
	Nitrogen (by difference), per cent	79.6	79.9	80.0	79.6	80.1	79.6	79.6	79.5	80.2
18	Mean temperature flue gases leaving boiler, °F	426	659	794	485	449	629	706	584	652
	STEAM AND FEED WATER.									
19	Gauge pressure, pounds per square inch	3	2	1	2	3	1	1	2	1
20	Temperature of feed water, °F	60	55	54	56	55	55	55	55	58
	RATES.									
21	Heat transferred to water per hour, 1,000 B. t. u	67	121	141	69	69	108	136	60	77
22	Heat transferred to water per square foot of heating surface per hour, B. t. u.	2,030	3,670	4,270	2,090	2,090	3,270	4,120	1,820	2,330
23	Fuel fired per square foot grate surface per hour, pounds	2.5	4.7	5.9	2.8	2.4	4.6	5.6	3.0	4.0
	HEAT BALANCE, PER POUND FUEL AS FIRED.									
24	Heat transferred to water, B. t. u	8,162	7,835	7,328	7,486	8,632	7,177	7,523	6,058	5,866
25	Heat carried away by steam in flue gases, B. t. u	119	122	138	112	272	299	319	606	611
26	Heat carried away by dry flue gases, B. t. u	1,454	2,500	3,131	2,418	1,663	2,009	2,256	3,972	4,426
27	Heat lost by not burning carbon monoxide, B. t. u	130	202	346	191	145	116	229	178	178
28	Heat lost by not burning carbonaceous matter from ash pit and grate, B. t. u.	132	55	32	119	199	1,194	1,010	136	120
29	Undetermined losses, B. t. u	1,417	782	425	1,209	1,160	377	1,099	867	764
	Total and calorific value of fuel, B. t. u	11,414	11,496	11,400	11,535	12,071	11,172	12,436	11,817	11,965
	HEAT BALANCE, PER CENT HEAT IN FUEL AS FIRED.									
30	Heat transferred to water (thermal efficiency)	71.5	68.2	64.3	64.9	71.5	64.2	60.5	51.3	49.0
31	Heat carried away by steam in flue gases	1.0	1.1	1.2	1.0	2.3	2.7	2.6	5.1	5.1
32	Heat carried away by dry flue gases	12.7	21.7	27.5	21.0	13.8	18.0	18.1	33.6	37.0
33	Heat lost by not burning carbon monoxide	1.1	1.8	3.0	1.7	1.2	1.0	1.8	1.5	1.5
34	Heat lost by not burning carbonaceous matter from ash pit and grate	1.2	.5	.3	1.0	1.6	10.7	8.1	1.2	1.0
35	Undetermined losses	12.5	6.7	3.7	10.4	9.6	3.4	8.9	7.3	6.4
	Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

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TABLE 6.—*Tests with Capitol boiler No. 257.*

Reference number.	General particulars.	Coke.			Anthracite.			Illinois bituminous coal.	
1	Number of trial	11	12	13	14	15	16	17	18
2	Duration of trial, hours	120	120	120	120	120	120.5	120	120
3	Average interval between firings, minutes	42	45	27	36	45	30	42	48
4	Fuel fired per hour, pounds	24	48	73	26	53	63	28	46
	FUEL.								
5	Ultimate analysis as fired:								
	Hydrogen, per cent	1.95	1.77	2.22	2.38	2.57	2.71	5.61	5.71
	Carbon, per cent	71.39	72.84	70.63	76.16	74.57	69.49	69.92	68.69
	Nitrogen, per cent	.77	.78	.81	.90	.88	.77	1.59	1.56
	Oxygen, per cent	12.90	11.36	14.97	3.71	5.48	6.64	16.57	17.85
	Sulphur, per cent	.80	.82	.73	1.21	1.19	.73	1.03	1.01
	Ash, per cent	12.19	12.43	10.64	15.64	15.31	19.66	5.28	5.18
6	Proximate analysis as fired:								
	Moisture, per cent	14.67	12.93	16.38	2.28	4.32	4.92	9.65	11.24
	Volatile matter, per cent	1.51	1.54	1.60	5.67	5.55	6.21	34.21	33.60
	Fixed carbon, per cent	71.63	73.10	71.38	76.41	74.82	69.21	50.86	49.98
	Ash, per cent	12.19	12.43	10.64	15.64	15.31	19.66	5.28	5.18
	Fuel ratio F. C./V. M.	47.4	47.5	44.6	13.5	13.5	11.1	1.5	1.5
7	Calorific value of fuel per pound:								
	As fired, B. t. u.	10,444	10,657	10,453	12,194	11,262	11,864	12,298	12,082
	Moisture and ash free, B. t. u.	14,279	14,279	14,344	14,855	14,839	14,839	14,456	14,456
8	Total fuel fired during trial, pounds	2,917	5,752	8,809	3,060	6,327	7,637	3,360	5,464
	ASH AND REFUSE.								
9	Total ash and refuse removed during trial, pounds	308	600	1,092	701	1,503	1,627	321	550
10	Carbonaceous matter in ash and refuse, per cent	6.49	4.67	8.06	28.39	15.69	22.37	9.28	5.84
11	Ash and refuse removed, per cent fuel as fired	10.56	10.43	12.40	22.91	23.76	21.30	9.55	10.07
	DRAFT.								
12	Draft in ash pit, inches water	0.046	0.032	0.031	0.013	0.034	0.014	0.014	0.016
13	Draft in furnace, inches water	0.055	0.063	0.069	0.040	0.089	0.086	0.020	0.049
14	Draft in stack, inches water	0.052	0.077	0.105	0.035	0.099	0.102	0.041	0.086
	AIR.								
15	Temperature air entering ash pit, °F.	70	80	82	69	81	92	77	79
16	Excess air in flue gas, per cent	86	53	32	56	54	28	60	75
	FLUE GASES.								
17	Analysis of dry flue gases by volume:								
	Carbon dioxide, per cent	10.2	11.3	13.1	11.9	12.3	14.4	11.2	10.1
	Oxygen, per cent	9.8	7.3	5.1	7.6	7.4	4.7	8.0	9.1
	Carbon monoxide, per cent	.2	1.8	2.4	.8	.6	.9	.7	.8
	Nitrogen (by difference), per cent.	79.8	79.6	79.4	79.7	79.7	80.0	80.1	80.0
18	Mean temperature flue gases leaving boiler, °F	398	587	788	430	748	852	524	686
	STEAM AND FEED WATER.								
19	Gauge pressure, pounds per square inch	2	2	2	2	2	2	2	2
20	Temperature of feed water, °F	52	54	53	50	55	51	53	51
	RATES.								
21	Heat transferred to water per hour, 1,000 B. t. u.	183	320	438	183	364	436	178	272
22	Heat transferred to water per square foot of heating surface per hour, B. t. u.	1,730	3,020	4,130	1,720	3,430	4,120	1,680	2,570
23	Fuel fired per square foot of grate surface per hour, pounds	2.8	5.5	8.5	2.9	6.1	7.3	3.2	5.3
	HEAT BALANCE, PER POUND FUEL AS FIRED.								
24	Heat transferred to water, B. t. u.	7,532	6,677	5,964	7,161	6,903	6,885	6,350	5,971
25	Heat carried away by steam in flue gases, B. t. u.	211	205	275	269	315	341	635	685
26	Heat carried away by dry flue gases, B. t. u.	1,388	1,915	2,077	1,431	2,317	2,058	1,653	2,473

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TABLE 6.—*Tests with Capitol boiler No. 257*—Continued.

Reference number.	General particulars.	Coke.			Anthracite.			Illinois bituminous coal.	
	HEAT BALANCE, PER POUND FUEL AS FIRED—Continued.								
27	Heat lost by not burning carbon monoxide, B. t. u.	138	1,009	1,094	445	334	386	412	507
28	Heat lost by not burning carbonaceous matter from ash pit and grate, B. t. u.	100	71	146	949	544	696	129	86
29	Undetermined losses, B. t. u.	1,075	780	897	1,947	849	1,498	3,119	2,360
	Total and calorific value of fuel, B. t. u.	10,444	10,657	10,453	12,194	11,262	11,864	12,298	12,082
	HEAT BALANCE, PER CENT HEAT IN FUEL AS FIRED.								
30	Heat transferred to water (thermal efficiency)	72.1	62.7	57.1	58.7	61.3	58.0	51.6	49.4
31	Heat carried away by steam influe gases	2.0	1.9	2.6	2.1	2.8	2.9	5.2	5.7
32	Heat carried away by dry flue gases	13.3	18.0	19.9	11.7	20.6	17.3	13.4	20.5
33	Heat lost by not burning carbon monoxide	1.3	9.5	10.5	3.6	3.0	3.3	3.4	4.2
34	Heat lost by not burning carbonaceous matter from ash pit and grate	1.0	.7	1.4	7.8	4.8	5.9	1.0	.7
35	Undetermined losses	10.3	7.2	8.5	16.1	7.5	12.6	25.4	19.5
	Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

The most important items are given in lines 22, 23, 24, and 30. Line 22 gives the average rate at which 1 square foot of the boiler heating-surface absorbed heat, the rate being expressed in B. t. u. per hour. The figures giving this rate of heat absorption indicate the rate of working the boiler, or the rating. On the low rating tests, the rate of heat absorption was nearly uniform throughout the entire 24-hour period. On the high rating tests, the rate of heat absorption during the 8-hour night periods was about the same as the rate on the low rating tests; and during the 16-hour day period it was higher than the average for the entire test given in the tables. Thus in test No. 6 of the Dunning boiler, the rate of heat absorption during the 8-hour night periods was about the same as the average rate in test No. 4 made with the same boiler. During the 16-hour day period the boiler absorbed heat at a somewhat higher rate than the average given in the table. That is, during the 8-hour night period, the boiler absorbed heat at the rate of about 1,630 B. t. u. per square foot of heating surface per hour, whereas during the 16-hour day period, it absorbed heat at an average rate of about 4,390 B. t. u.; thus the average for 24 hours was 3,470 B. t. u. Of course the rate of heat absorption varied during both periods; it was very low immediately after each firing, and gradually increased until it

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reached the maximum at a half an hour to two hours after firing; then it remained nearly constant for about half an hour; then gradually decreased.

What has been said about the rate of heat absorption holds true of the rate of combustion given in line 23. On the high-rating tests, less coal per hour was burned during the 8-hour night period and more during the 16-hour day period than is indicated by the figures in line 23. Therefore, in studying the results of the tests, one should give proper consideration to these conditions.

Line 24 gives the quantity of heat used to generate steam for each pound of coal fired, and represents therefore the useful effect of each fuel. The higher the figures in line 24, the more valuable is the fuel.

Line 30 gives the efficiency, or the proportion of the heat (in the fuel) that has been transferred to the water in the boiler. Thus in test No. 5 of the Dunning boiler, the efficiency is 71.4 per cent, which means that out of every 100 B. t. u. in the fuel fired, 71.4 B. t. u. were transferred to the water in the boiler and 28.6 B. t. u. were lost in various ways. Line 30, therefore, indicates what percentage of the heat in each of the four fuels tested can be utilized in house heating and how much heat is lost.

These efficiencies should always be considered together with the calorific or heat value of 1 pound of fuel as given in line 7. Although the efficiency of a fuel may be high, if the fuel contains a high percentage of ash and its heat value is low, the heating effect in the house-heating boiler may not be any greater than that of a fuel giving low efficiency but having high heat value.

LOSSES.

The last four items in the tables show where heat was lost. Those losses that are computed from the analysis and the temperature of the flue gases are only approximate, because the averages used in their computations were obtained on a time basis instead of on the weight of coal burned; that is, in the averaging, all the flue-gas temperature readings were given the same weight regardless of whether the rate of combustion was high or low when they were taken. The same is true of the flue-gas analysis. It has been previously stated that in most of the tests the fuel was burned at two different rates of combustion during each 24-hour period, at a low rate of combustion during the 8-hour night period and at a higher rate during the 16-hour day period. Even during the same period the rate of combustion varied between two successive firings.

To get a true average, the individual flue-gas temperature reading and the flue-gas analyses would have to be given proper weight ac-

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cording to the weight of coal burned during the periods represented by each reading. Such averaging is impossible on account of the extreme difficulty in obtaining the exact quantities of coal burned during each period. The values in the item representing the undetermined losses have been obtained by difference, and are rather erratic, because they contain all the errors of the other items.

The highest directly computed loss is much higher for Pittsburgh and Illinois coals than for anthracite or coke. This loss is due to high flue-gas temperature (item 18) and large excess of air. In the tests with anthracite the loss was about the same as in the tests with coke.

In the Dunning boiler, the gases pass through a jacket covering the entire boiler, and are therefore cooled to a much lower temperature than in the other boilers. For this reason, the loss due to heat being carried away in the flue gases is low, whereas the loss due to radiation, included in the undetermined losses, is high.

The loss due to the escape of unburned carbon monoxide is quite as high with coke as it is with the other fuels. The percentage of carbon monoxide in the flue gases is particularly high after a firing, before the top of the fuel bed becomes hot. The carbon monoxide is formed in the lower hot part of the fuel bed by the reduction of carbon dioxide in contact with the hot coke. As it passes through the upper layers of cold coke it is cooled below its ignition temperature, so that when it reaches the air above the fuel bed it does not burn, and passes into the stack. For this reason, whenever possible, part of the hot surface of the fuel bed should be left uncovered, so that the heat may ignite the carbon monoxide rising through the freshly fired coke.

The losses due to unburned carbon in the ash are highest in the tests with anthracite. This may be due to the fact that when anthracite is placed on the hot fuel bed, the rapid heating causes small chips of the coal to crack off and these find their way into the ash pit. Losses with coke from this cause are small.

RESULTS OF TESTS SHOWN GRAPHICALLY.

Figures 1 to 8 show the principal results of the tests graphically, plotted on the rates of heat absorption as abscissæ. The upper groups of curves in Figures 1, 2, 3, and 4 give the efficiencies obtained with the three fuels at different ratings of the boiler. The lower groups of curves show the percentage of heat carried away by chimney gases. In general, a low efficiency is accompanied by high flue-gas loss.

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The efficiency curves show, in a more striking way than the tables, what results can be obtained with any one of the three fuels when the boiler is operated at different ratings. In three of the boilers the coke generated steam more efficiently than anthracite, and in the fourth, the Dunning boiler, only at the higher ratings was the thermal efficiency with coke lower than with anthracite.

Figures 5, 6, 7 and 8, show the actual steaming values of each fuel at different rates of steaming. This steaming value is equal to the efficiency multiplied by the calorific value of each fuel. The Arco boiler tests (Fig. 5), showed the anthracite to be more economical

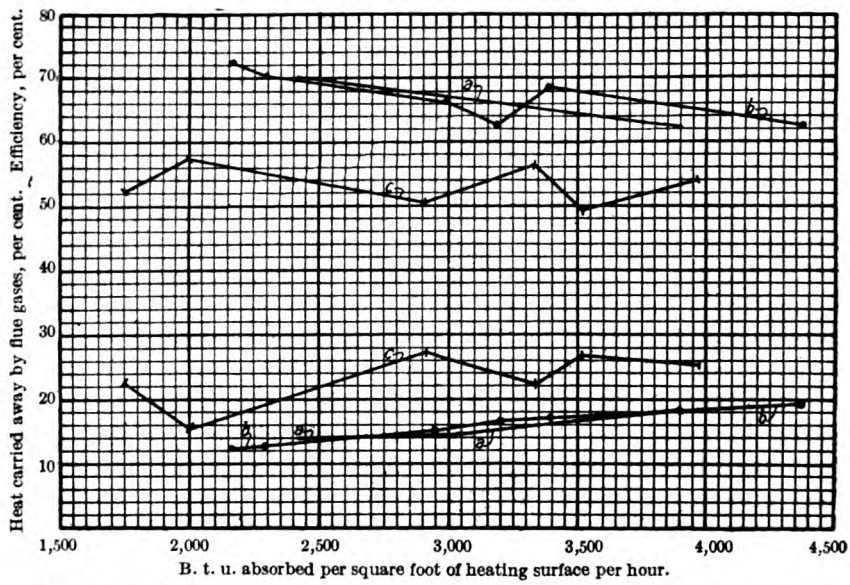

FIGURE 1.—Thermal efficiencies, and heat carried away by flue gases. Arco boiler tests: *a*, anthracite; *b*, coke; c, Pittsburgh coal.

than coke, which in turn was more economical than Pittsburgh coal. The Dunning boiler tests (Fig. 6), showed anthracite to have been better than either coke or Pittsburgh coal, which did not differ much. The Capitol boiler tests (Figs. 7 and 8), showed coke and anthracite to have about the same steaming value, and to be better than Illinois coal.

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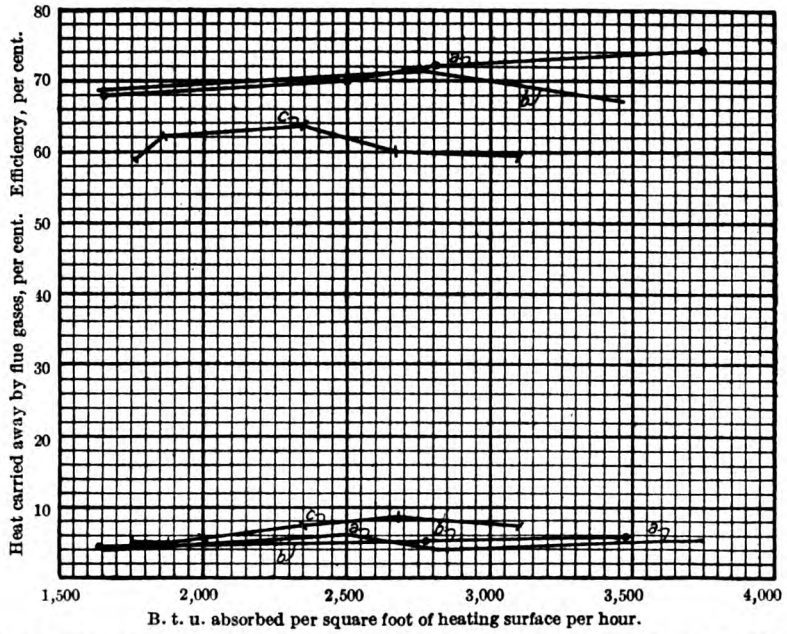

FIGURE 2.—Thermal efficiencies, and heat carried away by flue gases. Dunning boiler tests: *a*, anthracite; *b*, coke; *c*, Pittsburgh coal.

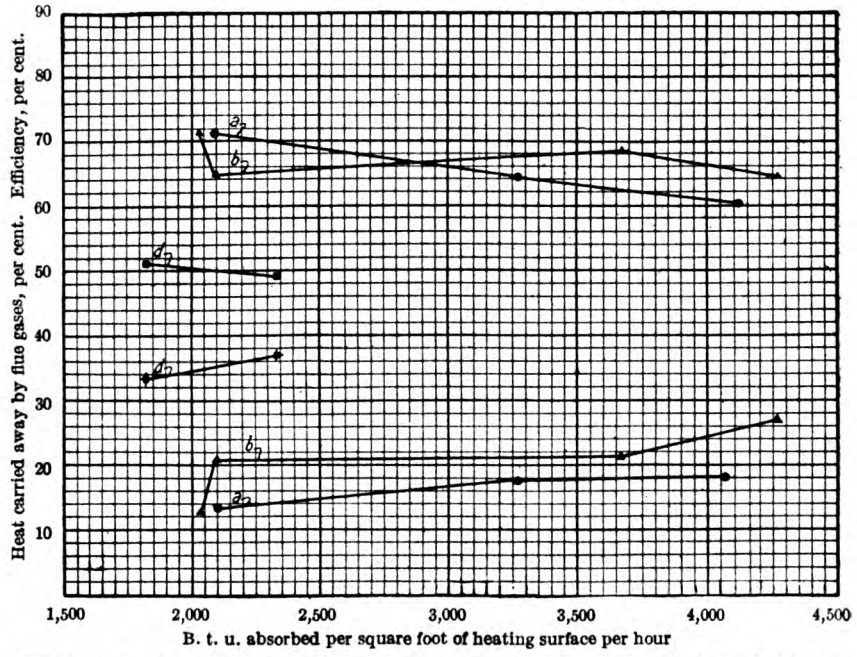

FIGURE 3.—Thermal efficiencies, and heat carried away by flue gases. Capitol Winchester boiler tests: *a*, anthracite; *b*, coke; *d*, Illinois coal.

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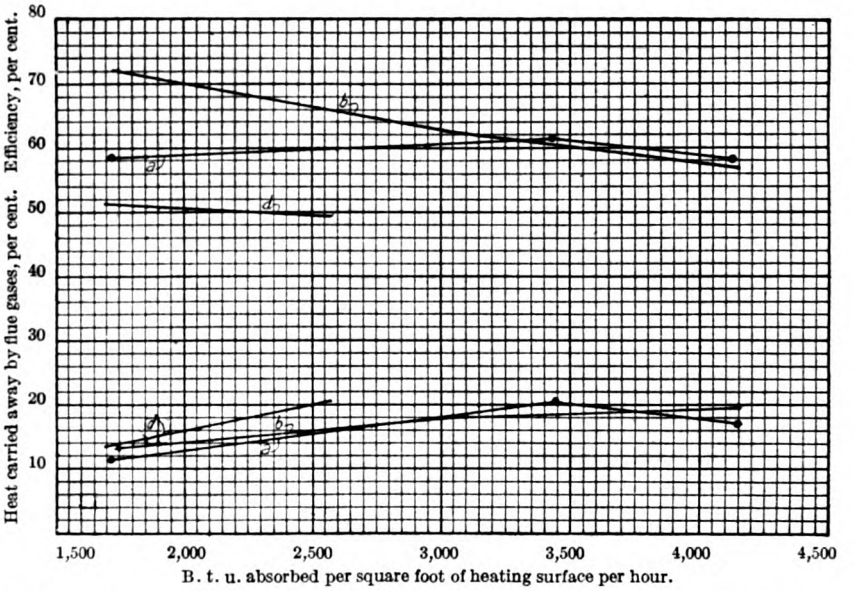

FIGURE 4.—Thermal efficiencies, and heat carried away by flue gases. Capitol boiler tests: *a*, anthracite *b*, coke; *d*, Illinois coal.

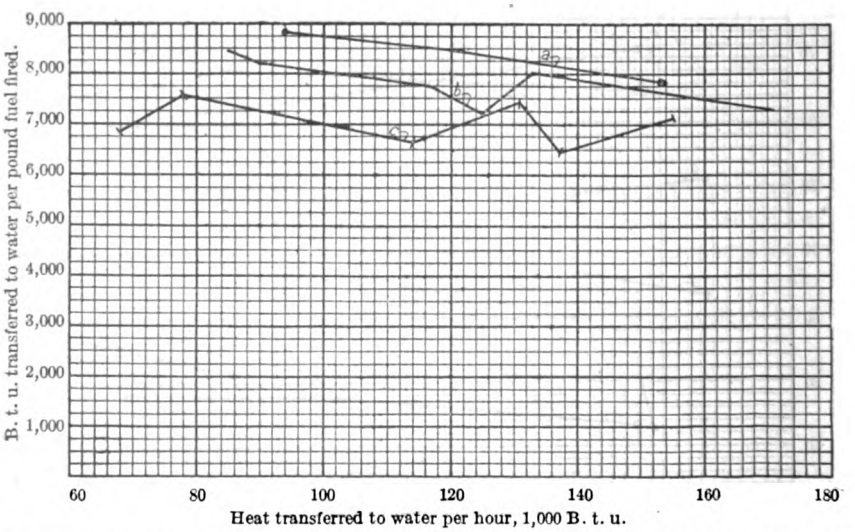

FIGURE 5.—Relative steaming values of fuels. Arco boiler tests: *a*, anthracite; *b*, coke; *c*, Pittsburgh coal.

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CLINKERING.

None of the three fuels gave particular trouble with clinker. Although the coke clinkered considerably more than any of the other fuels, the clinker was light and porous. It formed a circular disk covering the central part of the grate, and if the fire was not too hot, the whole disk was easily removed in one piece through the firing door. With a hot fire, the clinker was soft and broke into small pieces when an attempt was made to remove it. For this

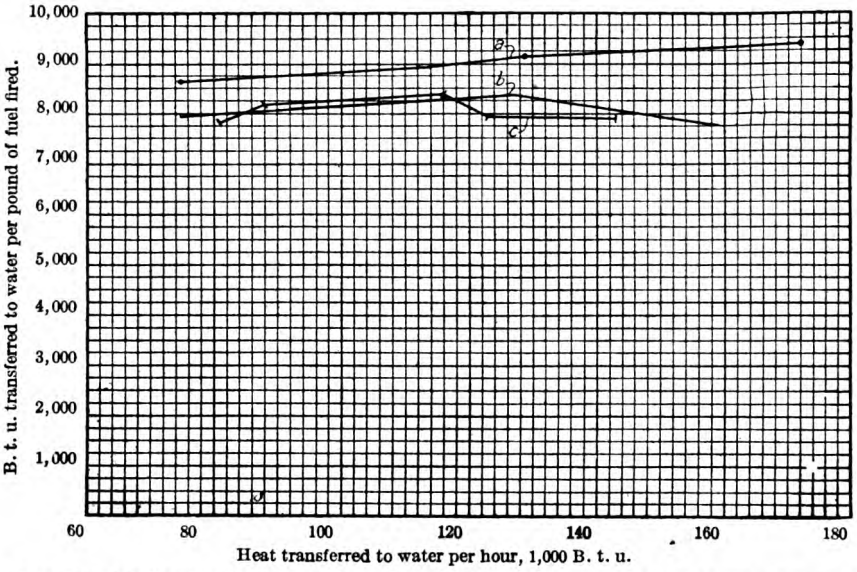

FIGURE 6.—Relative steaming values of fuels. Dunning boiler tests: *a*, anthracite; *b*, coke; *c*, Pittsburgh coal.

reason, the best time to clean the fire is in the morning when the fire is cool after the night period of low rate of combustion.

The Pittsburgh and Illinois coals made practically no clinker. However, to offset that, a heavy deposit of soot formed on the surfaces of the boiler. If good results are to be obtained, the soot should be swept off the boiler's surfaces frequently, preferably every morning.

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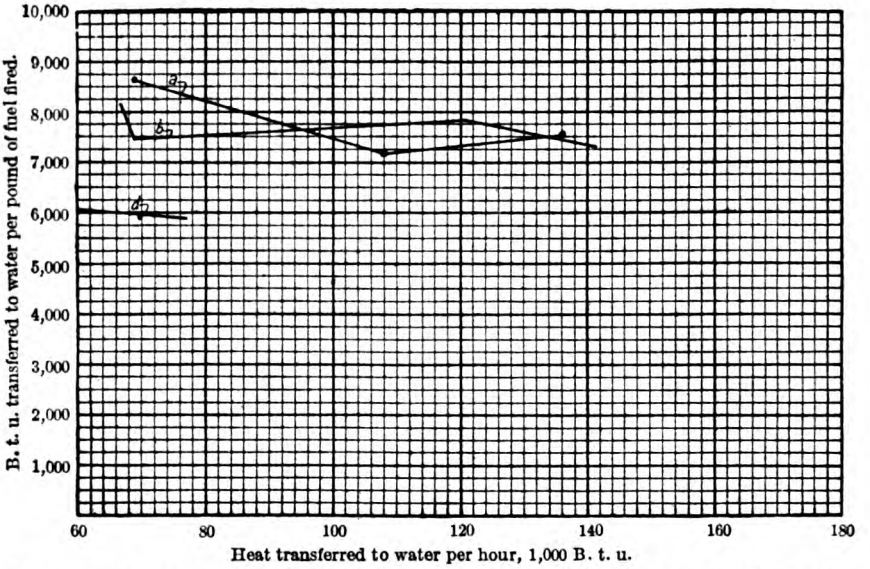

FIGURE 7.—Relative steaming value of fuels. Capitol Winchester boiler tests: *a*, anthracite; *b*, coke; *d*, Illinois coal.

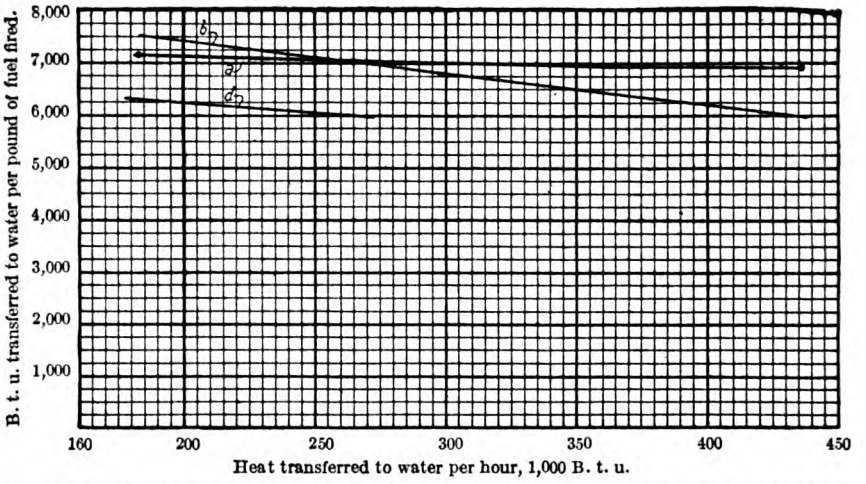

FIGURE 8.—Relative steaming value of fuels Capitol boiler tests: *a*, anthracite; *b*, coke; *d*, Illinois coal.

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RULES FOR BURNING COKE.

A complete set of instructions on how to burn coke in house-heating equipment has been given in Technical Paper 242.[2] The following rules contain the instructions in condensed form:

1. Carry a deep bed of fuel; one about 18 inches thick gives the best results.
2. Use very little draft after the fire is started, and keep it always under control. The success of even heating depends on careful draft regulation.
3. Do not stir the fuel bed; clean the fire in the morning.
4. Use sized coke: ½ to 2 inches for furnaces, boilers, and stoves; ½ to 4 inches for open grates.
5. Do not allow ash to accumulate in the ash pit.

PUBLICATIONS ON COAL AS BOILER FUEL.

A limited supply of the following publications of the Bureau of Mines is available for free distribution until the edition is exhausted. Requests for publications should be addressed to the Director, Bureau of Mines. The Bureau of Mines issues a list showing all its publications that are available for free distribution, as well as those that can be purchased from the Superintendent of Documents, Government Printing Office. Interested persons should apply to the Director, Bureau of Mines, for a copy of the latest list.

BULLETIN 129. The fusibility of coal ash and the determination of the softening temperature, by A. C. Fieldner, A. E. Hall, and A. L. Feild. 1918. 146 pp.

BULLETIN 135. Combustion of coal and design of furnaces, by Henry Kreisinger, C. E. Augustine, and F. K. Ovitz. 1917. 144 pp., 1 pl., 45 figs.

TECHNICAL PAPER 34. Experiments with furnaces for a hand-fired return tubular boiler, by S. B. Flagg, G. C. Cook, and F. E. Woodman. 1914. 32 pp., 1 pl., 4 figs.

TECHNICAL PAPER 80. Hand-firing soft coal under power-plant boilers, by Henry Kreisinger. 1915. 83 pp., 32 figs.

TECHNICAL PAPER 137. Combustion in the fuel bed of hand-fired furnaces, by Henry Kreisinger, F. K. Ovitz, and C. E. Augustine. 1916. 76 pp., 2 pls., 21 figs.

TECHNICAL PAPER 139. Low-rate combustion in fuel beds of hand-fired furnaces, by Henry Kreisinger, C. E. Augustine, and S. H. Katz. 1918. 54 pp., 19 figs.

TECHNICAL PAPER 180. Firing bituminous coals in large house-heating boilers, by S. B. Flagg. 1917. 22 pp., 1 pl., 16 figs.

TECHNICAL PAPER 205. Saving coal in boiler plants, by Henry Kreisinger. 1918. 24 pp., 3 figs.

TECHNICAL PAPER 207. Combustion experiments with North Dakota lignite, by Henry Kreisinger, C. E. Augustine, and W. C. Harpster. 1918. 44 pp., 1 pl., 13 figs.

TECHNICAL PAPER 217. Saving coal in steam power plants, by United States Fuel Administration. 1919. 8 pp., 1 fig.

TECHNICAL PAPER 219. Combustion and flue gas analysis, by United States Fuel Administration. 1919. 12 pp., 5 figs.

TECHNICAL PAPER 220. Burning steam sizes of anthracite, with or without admixture of soft coal, by United States Fuel Administration. 1919. 8 pp., 1 fig.

TECHNICAL PAPER 221. Saving steam in industrial heating systems, by United States Fuel Administration. 1919. 14 pp., 7 figs.

[2] Fieldner, A. C., and Kreisinger, Henry, Why and how coke should be used for domestic heating: Tech. Paper 242, Bureau of Mines. 1919. 20 pp.

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